ACTIVE EXCRETIONS OF PLANT ROOTS AND THEIR SIGNIFICANCE

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It has long been known that plants not only withdraw from the soil large quantities of nutrient substances, but also actively influence it: they promote the conversion of compounds difficultly accessible to the plant to readily utilizable forms, enrich the soil in organic substances, change the microflora of the rhizosphere, and make the soil more fertile. The active influence of plants on the soil is exerted primarily during the period of their intensive growth, which is due to their excretion through the roots of a number of organic and mineral compounds.

A large number of studies in the Soviet and foreign literature have been devoted to root excretions. At first they sought compounds that dissolve the substances of the soil difficultly accessible to the plants, as well as compounds that negatively affect the growth of certain plants in the case of repeated cultivation on the same spot. Pryanishnikov [1] indicated in his polemic article that the assertions that the accumulation of root excretions in the soil may cause soil depletion are unfounded.

During the last decade, investigations of root excretions have been directed chiefly toward a study of their chemical composition, especially toward the establishment of readiiy assimilable carbohydrate and nitrogeneous organic compounds and physiologically active substances, with the aid of which plants actively change the composition and activity of the root microflora and microflora around the root in a favorable direction.

The literature contains different viewpoints of the nature of the root excretions in plants. According to the assertions of Kostychev [2, 3], the main stimulus of exoosmosis of the root excretions in plants is the difference in the concentration of dissolved substances in the root tissues and in the medium surrounding them. The same viewpoint of the cause of exoosmosis of organic substances from the roots is also maintained by other researchers [4, 5]. The leading factor in the creation of a difference in their concentrations under natural conditions, according to the representations of Kostychev and his followers, is the continuous consumption of organic substances diffused out by the roots by the microbes swarming on the surface of the roots and on the soil particles adjoining them. He believes that microbes of the rhizosphere actively stimulate the production of various organic substances from the roots.

Avdonin [6] believes that the outflux of mineral compounds from the roots into the soil may occur only in the case when they are not bound by the organic substance in the plant cells and are present in a relative excess. According to the data of Chesnokov and Bazyrina [7], the main cause of exoosmosis of the root excretions in plants is a stimulation of the roots by the soil microorganisms.

The data concerning the amount of root excretions in plants are also contradictory. According to the data of Shulov [8], they comprise about 0.7% in sterile aqueous cultures, while according to Meshkov [9], they comprise no more than 0.25% of the weight of the plants excreting them. In the experiments of Chesnokov and Bazyrina [7], the root excretions of flax during its vegetation period comprised 131% of the weight of the dry mass of their roots in a sand culture under nonsterile conditions, and 186% in a soil culture. Mishustin and Naumova [10] believe that the mass of the root excretions in plants in farm plantings does not exceed 2.5 centners/hectare. Rudakov [11] essentially denies the presence of root excretions in plants as a normal physiological function of them. According to his assertions and those of certain other scientists, only the dead root hairs, exfoliated epithelial cells of the roots, and products of hydrolysis by bacteria of pectin substances contained in the intercellular fluids of the root may be included among the root excretions.

TABLE 1. Dimensions of Root Surrounding Gel-Like Caps and Root Caps in Higher Plants (in mm)

Plant	Classification of roots	No. of roots meas.	Gel-like caps		Root caps	
			diameter	length	diameter	length
Belotserkovskaya 198 winter wheat	Primary	31	0.81	0.95	0.31	0.19
Mironovskaya 808 winter wheat	"	30	0.90	1.01	0.35	0.21
Local winter wheat	"	105	0.60	0.74	0.24	0.23
Bukovinskii 8 corn	Main	16	1.28	1.54	0.43	0.18
" "	Lateral	23	1.06	1.41	0.36	0.20
Kievskii 8 corn	Main	18	1.54	2.04	0.55	0.20
" "	Lateral	24	1.19	1.38	0.39	0.19
Voronezhskaya corn	Main	28	1.95	2.31	0.50	0.39
" "	Lateral	78	0.99	1.48	0.23	0.21
Minskii corn	Main	52	2.31	3.22	0.59	0.42
Gomel'skii corn	Lateral	102	0.97	1.38	0.21	0.22
Local barley	Primary	63	0.42	0.48	0.23	0.21
Local oats	"	110	0.61	0.77	0.23	0.20
Ramonskii 77 peas	Main	61	1.03	2.32	0.48	0.17
" "	Lateral	24	0.78	1.66	0.27	0.16
Feed lupin	Lateral	32	0.99	2.12	0.21	0.33
Primorskaya 529 soybean	Lateral	100	0.80	1.25	0.25	0.23
Krasnodarskaya corn	Main	41	2.31	2.62	0.50	0.40
" "	Lateral	91	0.99	1.68	0.21	0.23

In an investigation of the composition of root excretions of different plants, the following were detected: sugars, organic acids, amino acids, enzymes, vitamins, toxins, elements of mineral nutrition, etc.

There are no experimental data in the literature on the zone of the root and form in which the indicated substances are diffused out by the plants. Meshkov [9] believes that the root surface, active in the absorption of nutrients, is simultaneously active in the exoosmosis of the root excretions; however, we find it difficult to agree with this viewpoint.

Recently studies have appeared in the literature, indicating that there are root excretions with a different character in plants, visible under a microscope. Kholodnyi [12], investigating roots of corn sprouts, stained with gentian violet after culturing in a moist air chamber with soil, established that the extreme 7-8 mm of them are coated by a layer of slime, in which there are individual or groups of plant cells, abjuncted by the surface of the root cap.

Geller [4, 13], who used treatment of the roots of plant sprouts in a solution of $KMnO_4$ and other oxidizing agents, arrived at the conclusion that the surface of the suction portion of the roots is covered with a unique multilayer cap of organic compounds, produced by the surface tissues of the growing roots.

Untilova [14] has shown that the tips of intensively growing roots in many agricultural plants excrete a colorless colloidal substance when cultured on moist filter paper and in soil, forming a special gel-like sac around the tip. Without staining it is invisible under a microscope, but it is quite evident after staining with a solution of methylene blue. A large number of plant cells, abjuncted by the root cap, are distinctly evident in the gel-like sac.

A broad layer of transparent, highly light-refracting substance, unstained by hematoxylin was observed on the surface of the meristematic zone of corn rootlets and those of certain agricultural plants by Trankovskii [15]. An analogous phenomenon was described earlier in the work of Guttenberg [16].

The importance of the gel-like substances produced by the root caps is extremely great and varied. Kholodnyi [12] was the first to show that in the slime covering the tips of corn roots, bacteria are entirely absent when the corn is cultured in a moist air chamber with soil, although there were very many of them in the zone of the root hairs. An analogous phenomenon, but in liquid nutrient medium, was observed by Rempe and Sorokina [17]. The toxicity of the root tips in a number of plants with respect to epiphytic and soil microbes was recently established by us in

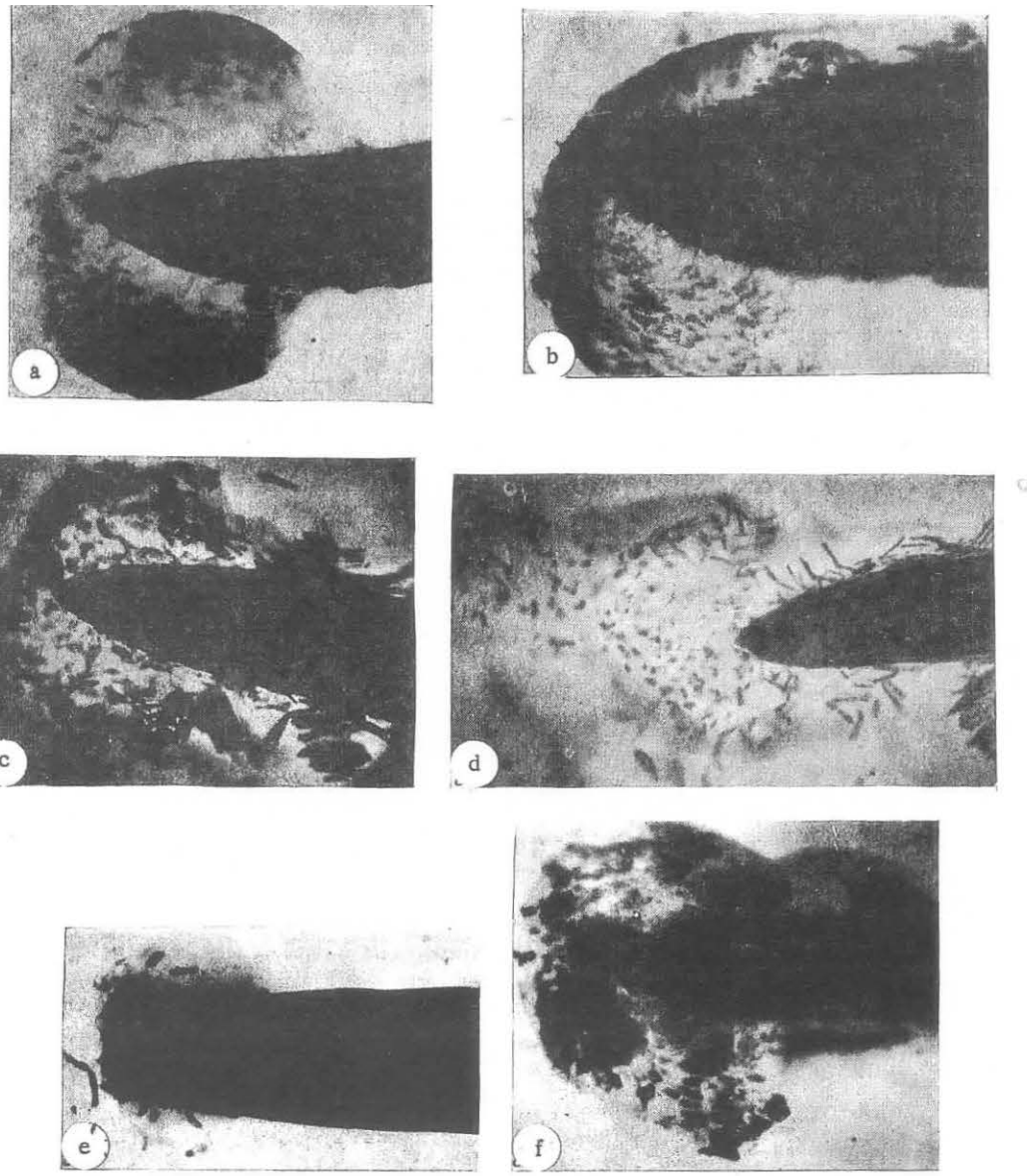

Fig. 1. Gel-like root caps in higher plants (× 35). a) Bukovinskaya 3 corn; b) Kievskii 8 corn; c) Primorskaya 529 soybean; d) Primorskaya 529 soybean; e) Belotserkovskaya 157 winter wheat; f) pendunculate oak.

special experiments [18]. Untilova [14] believes that the gel-like sacs promote penetration of the roots into the soil and enrich the soil in organic matter.

EXPERIMENTAL SECTION*

In a study of the population of the roots by microorganisms, we [18] noted that intensively growing, entirely untraumatized root tips, as a rule, are coated with a special cap, on which there are no microbes at all. It consists of a somewhat stretched, transparent substance; hence, it is microscopically indetectable in the unstained state.

* The investigations were begun at the Ukrainian Scientific Research Institute of Agriculture. The following took part in the experimental work: V. V. Rumyantseva, E. I. Ulashevich, L. F. Kagan, and A. A. Malama. We learned of the studies of Untilova [14] and Trankovskii [15] when a substantial portion of the investigations had been completed.

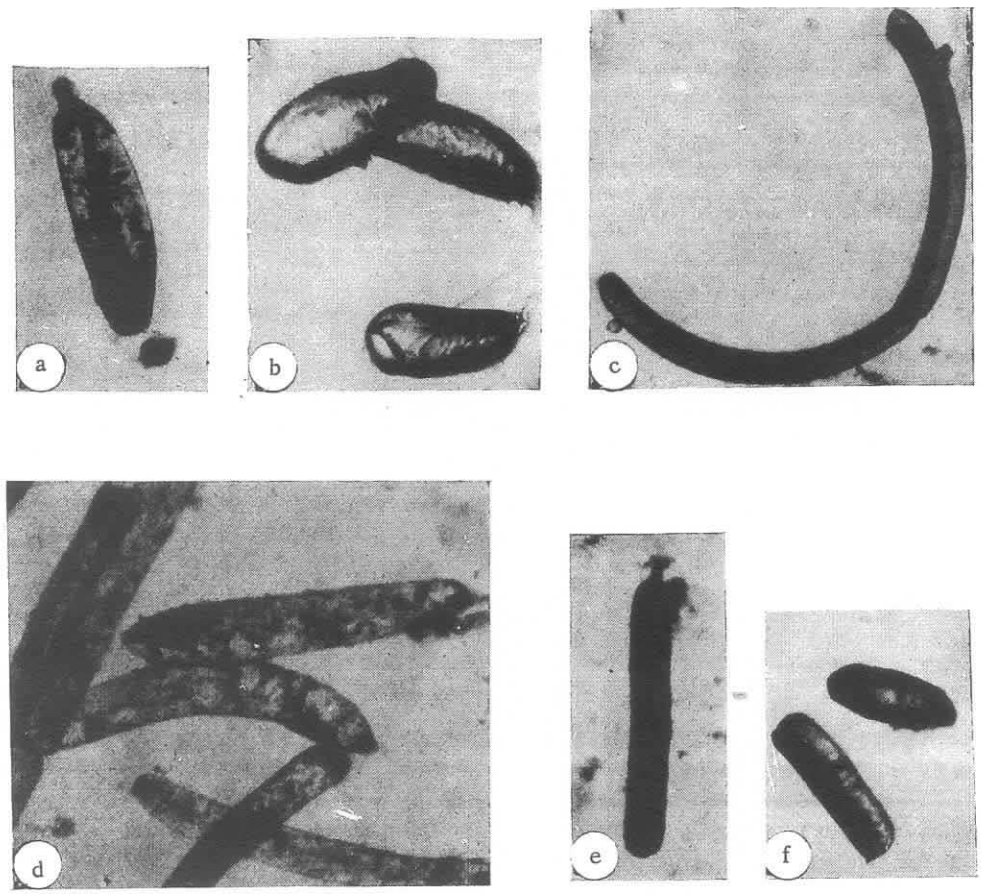

Fig. 2. Plant cells abjuncted by root caps in the root-surrounding gel-like cap (× 400). a) Corn; b) winter rye: c) sugar beet; d) soybean; e) feed lupine; f) alfalfa.

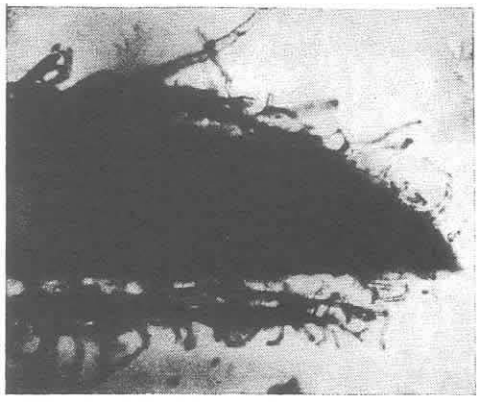

Fig. 3. Root tip of common pine (× 52.5). Explanations in text.

When the root tips are placed in a solution of methylene blue or gentian violet, the gel-like cap becomes readily visible under a microscope; in certain plants it is even visible to the naked eye. The gel-like cap usually is covered by the root cap, meristem, and zone of elongation of the cells, and sometimes also by part of the adjoining zone of root hairs, i.e., by all the most vulnerable, non-suberized, and most important part of the root.

The gel-like cap always contains the greatest number of individual plant cells, abjuncted, just like the gel-like substance itself, by the root cap. The plant cells are concentrated primarily near the margin of the cap, but, as a rule, do not go beyond it.

Almost all the intensively growing primary and lateral roots possess root-surrounding gel-like caps with plant cells within them when the plants are cultured on filter paper, in liquid nutrient media, in sand, and in soil, beginning with the first days of germination of the seeds, under sterile and nonsterile conditions. The gel-like caps are most readily visible in plants whose roots are growing upward, which we accomplished by culturing the plants in vessels with soil in a moist inner chamber (under a glass dome). The formation of gel-like caps on the root tips was observed at temperatures from 6-30°.

TABLE 2. Influence of the Nutrient Qualities of the Aqueous Solution on the Dimensions of the Root Surrounding Gel-Like Caps and Root Caps of Two Weak Sprouts of Plants (in mm)

Plant	Nutrient medium in which sprouts were cultured	Root surrounding gel-like caps		Root caps	
		diameter	length	diameter	length
Belotserkovskaya 198 winter wheat	Water	0.80	0.93	0.30	0.19
	Pryanishnikov's nutrient solution	0.81	1.24	0.30	0.20
	The same without N	0.81	1.12	0.29	0.17
Kievskii 8 corn	Water	1.30	1.46	0.44	0.19
	Pryanishnikov's nutrient solution	1.32	2.71	0.57	0.24
	The same without N	1.38	1.98	0.56	—
	The same without P	1.86	2.94	0.60	0.27
Ramonskii 77 peas	Water	0.79	2.06	0.42	0.13
	Pryanishnikov's nutrient solution with 0.5 standard of nitrogen	0.83	2.42	0.53	0.23
	The same without P	0.83	2.36	0.47	—

The shape and size of the root-surrounding gel-like caps, as is shown by Fig. 1, also differed among the same species of plant. When the roots passed through a layer of soil or other dense substrate, as well as in contact with them, the gel-like caps are subjected to deformation or are torn, as a result of which their contents are retained on the substrate, while the root, continuing its forward growth, again produces the same gel-like cap and abjuncts plant cells in it, etc. When the growth of the root has stopped on account of insufficient moisture, the secretion of the gel-like substance and the abjunction of plant cells in it by the root cap ceases, while the gel-like substance and cells secreted earlier are attached to the surface of the root and become microscopically indetectable. The plant cells in the root-enveloping caps of various plants differ greatly both in form and in size (Fig. 2).

We detected no gel-like cap in pine roots, but long strands of plant cells, emerging in all directions from all the root endings, were readily visible (Fig. 3).

In order to gain an idea of the amount of gel-like substances produced by the plant roots, we measured the diameter and length of the gel-like caps and root caps in a large number of roots of winter wheat, corn, rye, barley, oat, beets, peas, lupine, soybean, and other plants cultured under different conditions: on filter paper, on agar nutrient media, in water, sand, soil, and in a moist air chamber. No significant differences in the size of the caps were detected in culturing under different conditions. In the liquid medium, the caps are less compact, somewhat larger in size than in the moist air chamber; they do not take the stain as well, and their boundaries are weakly visible under a microscope. In legumes (peas, lupine, soybean), the gel-like caps are retained considerably more weakly on the root tips than in the nonleguminous plants, especially in the case of culturing in liquid media.

Table 1 presents the average dimensions of the root-surrounding gel-like caps and root caps of certain agricultural plants in their culturing in a moist air chamber and on filter paper in Koch dishes under nonsterile conditions.

As can be seen from the data cited, the diameter of the root-surrounding gel-like caps is 1.8-4.7 times greater than that of the root caps that produced them, while the length is 2.2-14 times greater. On the lateral rootlets, the diameter of the gel-like caps is somewhat smaller on the average than on the main roots.

An improvement of the mineral nutrition of young plants not only does not lead to any decrease in the size of the gel-like caps on their roots, but even somewhat increases them (Table 2), but since the roots of plants supplied with fertilizers are usually shorter and somewhat thicker, we should assume that the mass of the gel-like excretions, converted to one plant, will be smaller than in that of plants that have not received fertilizers.

On the basis of the fact that the gel-like substances are produced by all the root tips during the entire period of their growth, and, consequently, the length of the column that they form should be no less than the total length of the plant roots, we can calculate the mass of mucous substances and plant cells found in them that are produced by one plant or another in soil during the entire vegetation period per hectare. For this purpose we considered it possible to use the following formula:

$$(\pi r^2 \, RGC - \pi r^2 RC) \cdot TLR \cdot NP,$$

TABLE 3. Qualitative Reactions for the Presence of Carbohydrate and Nitrogenous Organic Compounds in the Gel-like Substance Produced by Corn Root Tips

Reaction	Resulting Reaction
Podobedov-Molish reaction with α-naphthol for carbohydrates	Sharply positive
Selivanov reaction with resorcinol for monosugars containing the ketose group	Negative
With ninhydrin for amino acids	The same
Biuret reaction for protein	" "
Lugol reaction for starch	" "
The same, but with precliminary addition of a little concentrated H_2SO_4	Stained in a violet color, characteristic of hemicelluloses

where πr^2 RGC is the average area of the root-surrounding gel-like cap; πr^2 RC is the average area of the root cap; TLR is the total length of the roots of one plant; NP is the number of plants per hectare.

Assuming the diameter of the RGC in wheat to be equal to an average of 0.80 mm, the diameter of the RC to 0.36 mm, length of the roots of one plant 500 m, and number of plants per hectare 3,500,000, we obtained the following volume for the total mass of gel-like substances in this crop per hectare: $(0.40\ mm^2 \cdot 3.14) - (0.18\ mm^2 \cdot 3.14) \cdot 500\ m \cdot 3{,}500{,}000 = 700\ m^3$. In corn it is even more: $(0.60\ mm^2 \cdot 3.14) - (0.20\ mm^2 \cdot 3.14) \cdot 25{,}000\ m \cdot 50{,}000 = 1250\ m^3$.

There is some basis for asserting that plantings of the indicated crops actually produce considerably more of the gel-like substances in the soil. According to Kolosov [19], the total length of the roots of one plant of spring wheat is 880 m, while in corn it is 46,800 m; we took only 500 and 25,000 m, respectively.

If we assume that the gel-like caps and plant cells found in them contain only 1% of the dry matter (we found up to 2% or more dry matter), then we find that the plants excrete into the soil no less dry matter than is contained in extremely high yields of grain of these crops (in winter wheat, 70 centners/hectare, in corn, 125 centners/hectare).

Perennial plants, the roots of which are in a state of growth for a longer period of the year in comparison with annuals (and a substantial portion of the roots, moreover, periodically dies out), should naturally excrete far more gel-like substances into the soil. This may explain the fact that plants grow better and their vegetation period is longer (for example, grass-legume mixtures) the greater the degree to which they enrich the soil in nutrient substances.

In order to determine the significance of the gel-like excretions of the root, we should naturally have at least some data on their properties and chemical composition. Moreover, we must emphasize that a study of the gel-like excretions of the roots presents extremely great difficulties: they are very difficult to obtain in unchanged form and amounts sufficient for investigation; they are difficult to separate from the root tips and do not dissolve in water at normal temperatures.

Here we cite only some preliminary data on the properties and composition of the gel-like excretions of corn roots. Investigations conducted in our laboratory by A. A. Malama have shown that the gel-like substance situated on the root tips, as a rule, is poorly detectable or entirely invisible under a microscope in phase contrast and in a dark field, which once again demonstrates the fact that its optical density and that of water are the same. The plant cells, on the other hand, are distinctly visible, which permits a judgment of the presence and magnitude of the gel-like cap.

The gel-like substance possesses greater sensitivity to many solvents. In water it dissolves only at high temperature: in 10 min at 70° and in 1 min about 95°. In ethanol, acetone, and a mixture of alcohol with ether, the gel-like cap, just as in the case of its drying in air, is greatly reduced in volume; its contents are attached to the surface of the root and cease to be visible under a microscope. However, if such a rootlet is placed in a drop of water, then after several minutes the gel-like substance again begins to swell; the cap is restored to its original size, and after staining becomes readily visible under a microscope. This indicates that the gel-like substance represents a hydrophilic colloid.

The gel-like substance of the root surrounding caps is extremely stable to acids and alkalis. The contours of the gel-like caps remain essentially unchanged under a microscope in 0.1 and 1.0 normal solutions of HCl and NaOH.

TABLE 4. Population of Root Tips of Plants by Saprophytic Microorganisms Under Conditions of a Moist Air Chamber

Microorganism	Winter wheat (51 experiments)		Corn (29 experiments)		Peas (22 experiments)		Winter rye (8 experiments)	
	investigated roots	proved sterile	investigated roots	proved sterile	investigated roots	proved sterile	investigated roots	proved sterile
Intrinsic epiphytic microflora	41	23	40	19	27	17	15	10
The same + complex of microflora of intrinsic rhizosphere	194	125	78	39	37	24	18	11
The same + Ps. fluorescens	29	13	30	18	31	25	10	6
The same + Bac. megaterium	30	22	24	20	—	—	—	—
The same + Az. chroococcum	28	10	24	14	—	—	—	—
Total: absolute	322	193	196	110	95	56	43	27
In %	100	59.9	100	56.1	100	59.0	100	62.4

Their form is also unchanged in the indicated solutions of NaOH even after 2 h, while the gel-like substance dissolves in HCl.

A study of the composition of the gel-like substance was conducted by the following method. The root tips were lowered into boiling water, in which the gel-like substance is readily soluble. The plant cells and other possible mechanical impurities were removed by centrifuging in a cooled solution. The low-molecular components of the solution were separated by dialysis through cellophane, after which three volumes of ethanol were added to the solution, and the mixture was left overnight in a refrigerator. The sodium precipitate formed was removed by centrifuging, washed with alcohol, dried in acetone, and stored until the investigation in a weighing bottle over calcium chloride.

The precipitate was investigated, according to [20], for a number of carbohydrate and nitrogenous organic compounds. The results of qualitative reactions, presented in Table 3, show that the gel-like substance of the root-surrounding cap of corn represents a polysaccharide, containing no protein, amino acids, and ketoses. It evidently contained hemicellulose.

The influence of the gel-like substances produced by the root tips of agricultural crops on the population of the root tips by epiphytic and soil microorganisms was studied in our special experiments [8]. The plant seeds were infected with a complex or individual species of epiphytic and soil microorganisms, and then, culturing for the plants, the passage of the microbes from the seeds to the root tips was determined. To avoid traumatizing the root tips, the seeds were germinated in a moist air chamber or on the surface of agar nutrient media. The presence of microbes on the root tips (transfer from the seeds) was judged by their growth in liquid nutrient media, into which sterile cut-off tips were transferred, or according to the absence of growth of microbes on solid nutrient media in places onto which growing rootlets were lowered from above.

As can be seen from the data of Table 4, in spite of the enormous amounts of microbes on the surface of the seeds and the great possibilities of their infection from other sources, in almost 60% of the root tips no microbes were detected.

On a smaller portion of root tips (about 40%), although microbes were detected, as a microscopic investigation showed, their numbers were negligible. Not only were no spore-bearing bacteria, actinomycetes, and fungi transferred to the root tips from the seeds, but there were not even any nonspore-bearing bacteria, taken from the zone near the roots of these same plants. In these same sprouts, in the zone of the root hairs, just as on the tips of the roots that had stopped growing, microbes were always found in large quantities.

The data on the high resistance of the roots to population by microorganisms, obtained under laboratory conditions, are well correlated with the data of an investigation of the soil microflora under plants and under field conditions. As evidence, let us cite the data of three-year investigations of the effects of liming on the microflora of the rhizosphere of corn, conducted in our laboratory by E. I. Ulashevich.

TABLE 5. Changes in the Total Amount of Bacteria in Turf-Podzol Sandy Loam Soil During its Liming Under Corn

Soil	Number of investigations	Soil, control (outside rhizosphere)	Rhizosphere		Layer of soil near roots		Roots	
			in % of control	abs. amount	in % of control	abs. amount	in % of control	abs. amount
			Sprouts					
Nonlimed	3	1.6	2.8	175	13.3	831	3.8	238
Limed	10	2.8	3.7	132	28.1	1003	2.5	89
			Blooming					
Nonlimed	3	1.7	3.3	194	61.4	3612	21.4	1259
Limed	10	4.8	6.0	125	89.6	1862	11.6	242
			Milky ripeness					
Nonlimed	3	3.9	4.5	115	50.5	1295	11.0	282
Limed	10	5.5	7.1	129	75.6	1375	7.0	127

(The yield of green mass of corn on nonlimed soil was 575 centners/hectare, on limed soil 656 centners/hectare.)

As can be seen from the data of Table 5, the total number of bacteria on corn roots germinated on limed soil is far smaller than on nonlimed soil, both absolutely and relatively. In the layer of soil near the roots on limed soil, the absolute number is substantially greater than on nonlimed soil, but with respect to the control—the soil outside the rhizosphere—there are somewhat fewer of them on the average. Relatively fewer bacteria on limed soil were also found in the rhizosphere. This pattern is manifested especially distinctly in the phase of blooming of the plants, when the latter possess the greatest vital activity. Later, when the growth of the roots slows down, and, when in connection with this, their immunity is reduced, the difference in the influence of the roots of corn on microorganisms on limed and nonlimed soils is smoothed out.

The literature already contains many data on the negative effect of saprophytic microorganisms on the growth of plant roots. It is most graphically manifested in the presence of a deficiency or excess in the soil of one of the basic elements of nutrition or energy source (primarily carbohydrate or nitrogenous substances), required in large quantities both by the microorganisms and by the plants [21, 22].

Investigations have shown that the high toxicity of the contents of the roots is even characteristic with respect to such specific microorganisms for them as rhizobia.

In view of the antimicrobial properties of growing root tips, their participation in the absorption of nutrient substances is of great interest. The literature contains many studies devoted to this problem. Kolosov [19], whose monograph presents a detailed exposition of these data, also arrived at the conclusion that "root tips up to 6-7 mm (cap and meristem) do not take part in the absorption of substances."

Thus, the gel-like substance surrounding the tips of growing roots not only protects the latter from their mass population by antagonistic microbes, but also retards the entry of nutrient substances into the roots from the medium surrounding them. There is no doubt that from the evolutionary standpoint, the positive and most important property of the gel-like substance for plants can only be its toxicity. No little role in the maintenance of this property of the gel-like substance, in our opinion, is played by the plant cells found in it.

When plants are grown in soil, the significance of the gel-like substances produced by the root tips is far broader than when they are grown in water cultures or in a moist air chamber. With the aid of the gel-like substances, the plant moistens those portions of the soil along which the roots should move ahead, reduces the resistance to their motion in the soil, neutralizes the reaction of the layer of soil near the roots, enriches the soil in organic and mineral substances, and makes it structured. The gel-like substances increase the contact between the root hairs of the soil; some roots are enabled to grow in the soil interlayers with insufficient moisture content on account of the activity of other roots growing under conditions of sufficient moistening; moreover, part of the gel-like substances are reutilized by the roots of the same or neighboring plants in a form reprocessed by microbes (and perhaps in nonreprocessed form as well).

Thus, on account of the assimilation of solar energy by the green leaf, a circulation of substances is accomplished not only within the plant [23, 24], but also between the plant, microorganisms, and the soil, which promotes better growth both of the excreting plant itself and of its subsequent generations in this site.

CONCLUSIONS

1. In most plants the root tips (root cap, meristem, and zone of elongation of cells) are covered by a special cap, consisting of a colorless gel-like substance with a large quantity of individual plant cells within it, produced by the root caps during their growth.

The gel-like caps are microscopically indetectable in unstained form, but they are rather readily visible when the roots are stained with many dyes.

2. The shape and size of the gel-like caps differ in different plants and even in one plant. According to tentative calculations, the roots of winter wheat produce no less than 700 m^3 of gel-like substance per hectare in the soil during the summer, while those of corn produce more than 1250 m^3/hectare.

The gel-like root-protecting substances possess dry matter equal to that in extremely high yields of grain of the indicated crops.

3. The contents of the gel-like caps are extremely stable to external conditions. In corn the gel-like substance is insoluble in water up to 50-60°, as well as in solutions of HCl and NaOH. In alcohol, acetone, and a mixture of alcohol with ether, the gel-like substance is rapidly dehydrated, affixed to the roots, but when placed in water is again restored to its previous dimensions.

4. The composition of the gel-like excretions of the roots differs from the composition of the root excretions of plants known in the literature. The gel-like excretions of corn roots give negative reactions for sugars, amino acids, proteins, and starch, and a positive reaction for hemicellulose.

5. The denser and more prolonged the coverage of soil by green plants and the better they grow, the more gel-like substances they excrete into the soil, and the more arable the soil becomes. There is some basis for believing that the gel-like substances excreted by the roots are the most important basis for the active humus formed in the soil under plants.

6. The significance of the root-protecting gel-like substances of plants is extremely great and manifold. They facilitate penetration of the roots into the soil, enrich the rhizosphere in organic substances, protect the growing nonsuberized root tips from mechanical injury by the soil particles and their massive infestation by antagonistic microbes, and increase the contact of the root hairs with the soil particles.

7. The study of the gel-like excretions of plant roots must be paid considerably greater attention by scientists of varied specialities: phytophysiologists, microbiologists, biochemists, soil scientists, etc.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.